A Guide for the Dissection of the Dogfish (Squalus Acanthias)

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The small sharks which abound along the coasts of the United States are commonly called "dogfish" by fishermen and others. The "dogfish" of inland waters belongs to an entirely different group. Two species of sharks are caught in numbers and used in laboratory work, the "spiny dogfish" (Squalus acanthias) and the "smooth dogfish" (Eugaleus galeus). The first is easily distinguished by the sharp spine in front of each dorsal fin. Squalus acanthias is often referred to under the synonym Acanthias vulgaris, while Eugaleus galeus is more frequently named either Mustelus canis or Galeus canis. The histories of these names and systematic descriptions of the species are contained in Samuel Garman's Monograph on the Elasmobranchs.

Several sizes of dogfish are furnished by dealers. We consider it best to purchase large, fully developed specimens. The small specimens may be a little more convenient to handle, but the large ones have the important advantage of being sexually mature, while blood vessels and nerves are dissected better in large than in small specimens. Also, a number of structures are very different in mature animals from their condition in young ones. Dealers should be requested to furnish fish with fins and tails complete instead of trimmed. It is an advantage to issue to the class equal numbers of both sexes.

An entire specimen and an extra head may be required by each student for a thorough dissection. It would be better if the head were cut off just behind the pectoral fins, instead of in front of them as is usually done, so that the vagus and hypobranchial nerves may be dissected more completely.

The spiny dogfish, which is the particular subject of this guide, is the species most frequently supplied to laboratories. However, the spiny and smooth dogfishes are so much alike that the latter may be easily dissected with these directions. Where marked differences between the forms exist the structure of Eugaleus is described separately.

The student of anatomy should realize that dissection is for the purpose of enabling him to see for himself the structures which exist, and that no dissection is satisfactory until the anatomical arrangements mentioned in the text can be completely demonstrated in his specimen.

The importance of knowing the structure of the elasmobranch is so great in comparative anatomy and embryology that it is worth while to make a thorough dissection of one of this class. As the dogfish is frequently the first major vertebrate form to be studied in detail, these directions have been written to conform to the needs of the student who is beginning comparative anatomy. The arrangement of sections in this guide is intended to permit the omission of some which it may not be considered desirable to include in the work of a class.

EXTERNAL CHARACTERS

The spindle-shaped body tapers from near the middle toward both head and tail; the head is flattened on both the dorsal and ventral sides, while the remainder of the body is nearly round, with a lateral compression which is not pronounced except in the caudal portion.

The general color of the back and sides is gray; darkest above, where the skin is spotted with scattered, small, round, light spots. The color of the upper parts shades into the yellow white of the ventral surface.

Can head, trunk, and tail regions be distinguished? If so, what characters determine the extent of each?

A little above the middle of the side of the body is the *lateral line*, (distinguished partly by color, partly by being slightly elevated), which extends from the back of the head to the tail. Cut through the skin across the lateral line at several points along the body and notice the canal which lies in the dermis under the lateral line. This is the *lateral line canal*, which opens to the surface by numerous pores (too minute to be seen), and contains a series of special sense organs along its dorsal and inner surfaces. Near the base of the caudal fin the lateral line canal passes into a groove which continues the lateral line to within a short distance of the edge of the fin. The lateral line canal in its development begins as a groove along the side of the body which becomes closed by the fusion of its edge except in this terminal portion.

The open groove does not appear in Eugaleus.

In the midline of the body are two triangular *dorsal fins*, each attached to the body for about half its length. The basal portion of each is thick and muscular, and contains supporting cartilages embedded in the muscles. The remainder of the fin is flexible and semi-transparent, horny finrays being faintly visible between the layers of skin. In front of each fin is a strong spine which seems to serve both as a cutwater and a weapon of defense. (Eugaleus has no spines.)

The broad, paired, *pectoral fins*, having the general characteristics of the dorsals, spring from the ventral edges of the body just back of the head. A hard bar of cartilage connecting the bases of the pectoral fins can be felt through the skin of the ventral surface of the body. This is the ventral part of the *pectoral girdle*.

Farther back, and also on the ventral surface, are the paired *pelvic fins*. The pelvic girdle can be felt through the skin between the bases of these fins. If the specimen is a male, it will have a fingerlike process projecting backward from the base and along the inner side of each pelvic fin. These organs, which attain a considerable size in adults, are modified portions of the pelvic fin used as copulatory organs. They are named variously *claspers*, myxopterygia, or pterygopodia. A groove runs along the dorsal side of the clasper from the tip to near the base, where it opens into a long sac (*glandula pterygopodia*) extending some distance in front of the pelvic fins just within the skin of the ventral surface. By feeling a cartilaginous axis of the clasper can be discovered, which extends to the tip of the organ. On the dorsal surface and near the end of the clasper is a sharp grooved spine on the outer side, and a strongly recurved hook on the inner side, both almost hidden by a flap projecting from the inner edge of the groove. This flap is stiffened by a series of small cartilages similar to the radial cartilages in the bases of the fins.

The *caudal fin* is asymmetrical, extending along the dorsal and ventral edges of the posterior end of the body. Observe the upward bend of the vertebral column which occurs in the tail; it is this character which marks the heterocercal type of tail.

Eugaleus has a median ventral, or *anal,* fin a short distance anterior to the caudal fin.

The *mouth* is a broad transverse slit upon the ventral surface of the head. The cartilaginous jaws can be seen and felt just within the mouth. Both upper and lower jaws are armed with rows of flat, sharply pointed teeth. Study their arrangement and approximate number. Jaws of previously dissected specimens should be examined under a dissection miscroscope. The exact form and arrangement of the functional teeth can then be ascertained easily, and an examination of the inner surface of either jaw will disclose several rows of developing teeth. As the young teeth develop they move, a row at a time, into position on the edge of the jaw; the oldest teeth, occupying the outer row, are shed at about the same time.

The upper jaw is partly overhung by a lip-like fold of skin. At each side of the mouth is a pocket, directed obliquely, having no communication with the mouth. These *labial pockets* provide places for the *labial cartilages* (which can be felt along the medial edges) when the mouth is closed, and also afford freedom of motion to the mandible. Cut along the inner edge of the labial pocket and expose the cartilages for examination. (The labial pocket of Eugaleus is much smaller, and in front of the corner of the mouth rather than lateral to it. The two cartilages are completely separated from each other, the posterior one scarcely reaching the pocket.)

In front of the mouth are the *nostrils,* their apertures apparently divided by projecting flaps of the anterior margin. Explore the cavity of the nostril with a probe to get a good idea of its size and form.

Between the pelvic fins is the *cloaca,* a large depression into which open the alimentary canal, the excretory and genital ducts, and the abdominal pores. The opening of the alimentary canal, the *anus,* is at the anterior end of the cloaca. In preserved specimens part of the intestine is frequently everted through the anus. A large fleshy process, bearing a pore at its tip, projects from the dorsal wall of the cloaca. In the male this is the *urogenital papilla;* in the female the *urinary papilla.* In the female a *genital pore,* the opening of the oviduct, is found on either side of the papilla. An *abdominal pore,* leading into the abdominal cavity, is found on each side of the cloaca at the posterior margin. These are frequently closed in young specimens.

The cloaca of Eugaleus has a comparatively small opening upon the ventral surface, which must be enlarged before the parts described can be seen well.

The laterally placed *eyes* are without lids; observe the considerable difference in the amount of curvature of the dorsal and ventral margins of the eye.

In Eugaleus there is a fold of skin stretched across the lower part of the eye which serves as an eye-lid, and corresponds to the so-called "third eye-lid" or nictitating membrane of other vertebrates.

On each side of the neck are five vertical *gill-clefts,* each leading into a large *gill-pouch* which communicates with the pharynx by an internal opening. Pass a probe through a gill-cleft into the mouth.

Back of each eye is a small aperture, the *spiracle;* explore this cavity with a probe. The spiracle is to be considered a gill-cleft moved forward upon the head and largely, though not entirely, deprived of its respiratory functions.

In the center of the dorsal surface of the head, between the

spiracles, are two pores, the *external openings of the endolymphatic ducts* which communicate with the internal ear. Large numbers of smaller pores can be found on all surfaces of the head, some in groups, some arranged linearly, many scattered. Most of those arranged in lines lead into the sensory canal system which continues from the lateral line canal upon the head, while the majority of the others belong to a separate type of sense organs, the *ampullae of Lorenzini.*

Make a cut encircling the pores of the endolymphatic ducts and close to them. Do not remove this piece of skin. From it make a median incision forward to the tip of the snout and back as far as the level of the first gill slit. Starting at this incision work the skin off from the tissues beneath it. This must be a careful, close dissection. When the lateral line is reached it will be seen that the lateral line canal is continued upon the head and is joined by several others. By looking through the loosened skin toward the light the pores can be seen which lead from the canals to the surface. In the hollow of the skull in front of and above the eye is a large group of tubules which open through the pores so conspicuous at this point. At the internal end of each tubule is a slight enlargement, of denser tissue, with which a delicate nerve strand can often be seen connected. The nerve strands can be traced to a large nerve passing above the eye and distributed to the snout. These tubules are the *ampullae of Lorenzini.* This group of ampullae, which may be called the dorsal group, is quite definitely demarked. It will be noted that the inner ends of the ampullae are grouped in a much smaller area than their pores.

Between the spiracle and the first gill slit will be found a lateral group of similar organs. Notice the arrangement of their tubules and pores. Under the snout are two groups of ampullae on each side of the midline. The inner ventral group is separated from the outer ventral group by the lateral bar of the rostral cartilage. Some of the tubules of the outer ventral group will be found to extend to pores situated at the sides of and behind the mouth.

An adult fish possesses from 1200 to 1900 ampullae of Lorenzini. Their function is not well understood, but it has been suggested that they are organs responsive to stimuli of pressure, either of currents or water, or resulting from depth, or even of deep tones.

The *system of sensory canals* consists of the following members on each side of the head:—

A *supraorbital,* passing above the eye to the end of the snout and bending back on the ventral surface to join the infra-orbital.

An *infra-orbital,* which branches off from the supra-orbital and passes ventrad between the eye and the spiracle, then turns forward along the ventral margin of the orbit, and finally bends toward the mid-line and extends to the tip of the snout.

A *hyomandibular,* which leaves the infra-orbital below the eye and runs back beyond the angle of the mouth.

A short *mandibular,* on the mandible close to the angle of the mouth, which is not connected with the other canals.

The canal systems of the right and left sides are connected by a *supra-temporal* canal just behind the endolymphatic pores, and often by an anastomosis of the infra-orbital canals in front of the mouth.

On some specimens two crescentic rows of pores can be found between the bases of the pectoral fins, which represent a third type

of sensory organ, the *pit organs,* closely related genetically to the sensory canals. Two longer lines of pit organs, (the *mandibular pit organs*), will be found a short distance behind the mouth. Similar pit organs are found in front of the endolymphatic pores, and above the anterior part of the lateral line.

Except for a few small areas the entire surface of the body is covered with small, sharp-pointed denticles (*placoid scales*). Each consists of a diamond-shaped basal plate embedded in the dermis, from which projects a leaf-like, backward directed spine. A piece of skin should be removed and examined under a low magnification. The dermis is so dense and pigmented that the basal plate is not easily studied without further manipulation. For this purpose boil a piece of skin in 5% caustic potash solution until it is softened, but not till it disintegrates. Then clear it in glycerine. Examine the individual denticles under a higher magnification. The denticle consists of dentine, the spine being of a much denser structure than the base. The teeth and the large spines of the fins and claspers are also composed of dentine and may be considered as modified placoid scales. Denticles, teeth, and spines are covered with a shiny, enamel-like layer which, however, does not appear to be true enamel such as covers the teeth of higher vertebrates. The shape of the scales and their closeness vary on different regions of the body, and there are certain regions entirely free from them, namely, back of the dorsal, pectoral and pelvic fins, the medio-dorsal surfaces of the claspers, inside the upper lip and the labial pockets.

DISSECTION OF THE ABDOMINAL VISCERA

Place the dogfish on its back and, commencing at the middle of the abdomen, make an incision through the body wall a quarter of an inch to one side of the midline. Carry this forward to the pectoral girdle and backward through the pelvic girdle to the cloaca; not, however, cutting the wall of the cloaca.

A large vein, the *lateral vein,* runs along the inner surface of each lateral wall of the abdomen. After identifying these, cut through the body wall transversely on both sides of the abdomen at the level of the posterior attachment of the pectoral fin as far as the lateral vein. Turn the flaps outward and fasten.

The *coelom or body-cavity* consists of two portions, the abdominal and pericardial cavities. The *abdominal cavity,* which has now been opened, extends from the pectoral girdle to the cloaca and along the sides of the latter; it communicates with the exterior through the abdominal pores on either side of the cloaca. Pass a bristle or probe through each abdominal pore into the cloaca.

Without dissecting, identify the following parts and observe their relations:

The *peritoneum,* the smooth lining of the body-wall, which is reflected over the viscera.

The *liver,* a large, gray organ attached anteriorly and almost completely divided into two lobes which extend well back along the sides of the abdominal cavity.

The *stomach,* lying between the lobes of the liver. Its posterior end is bent forward upon itself in the form of a U. The two limbs of the stomach are known as the cardiac (proximal) and pyloric (distal), respectively. With a second turn to the right and backward it enters the intestine.

The *intestine,* a large, thin-walled tube extending from the stomach to the cloaca.

The *spleen,* a dark, triangular mass attached to the posterior border of the curve of the stomach.

The spleen of Eugaleus is a long, slender body extending from the middle of the proximal limb of the stomach around the posterior end of that organ and forward again along the distal limb for two-thirds of the length of the latter.

The *pancreas,* a firm white mass the larger part of which lies dorsal to the posterior end of the stomach. One extremity lies on the ventral surface of the junction of the stomach and intestine.

The *reproductive glands,* (ovaries or testes), lying on either side of the midline dorsal to the anterior portion of the liver; they may be mistaken for small lobes of the liver.

The reproductive glands of Eugaleus are long bodies lying above the stomach and intestine. They are fused to each other for almost their entire length.

The *kidneys,* two long, slender, brownish bodies extending along the dorsal wall of the abdominal cavity outside the peritoneum, on either side of the midline.

The dogfish usually furnished for dissection are immature, having the genital glands and ducts only partly developed. In mature females the *oviducts* are conspicuous tubes ventral to the kidneys. In young specimens they appear as slender, white tubes extending along the inner borders of the kidneys. Anteriorly, the oviducts pass ventrad over the front of the liver to the ventral wall of the body; at the same time they unite to form a funnel, the *ostium tubae,* which opens into the coelom. Vestigial oviducts opening into the coelom are found in the same position in males.

In males, the *vasa deferentia* appear as slender, irregularly coiled white tubules lying near the medial border of the kidneys; they are much less conspicuous than the oviducts, especially in young males.

THE ALIMENTARY SYSTEM. In dissecting the following organs, care should be taken not to break the connections of the organs with each other or with other parts, or to cut blood vessels. Organs should not be removed until such procedure is directed.

The mouth and pharynx can be studied to better advantage later with the dissection of portions of the vascular system.

The *oesophagus* can be seen above the liver, by pressing that organ aside, as a somewhat constricted tube entering the anterior end of the abdominal cavity. It immediately joins the stomach, which is more or less expanded according to the amount of food contained in it.

The *stomach* passes directly back for more than half of the length of the abdominal cavity, then turns abruptly forward, forming a distal limb about a third as long as the proximal. (Two-thirds to three-quarters as long in Eugaleus.) The distal limb ends with a sharp turn to the right, where it is constricted by the *pyloric sphincter,* which marks the end of the stomach.

The narrow beginning of the intestine forming the turn to the right and backward is frequently distinguished as the *duodenum.* It leads from the stomach directly into the *large intestine,* a wide, straight tube marked externally by a spiral line of several turns. The large intestine narrows posteriorly, forming a region somewhat arbitrarily termed the *rectum,* which opens into the cloaca through the anus.

Dorsal to the rectum and attached to that body is a narrow spindle-shaped body, the *rectal* or *digitiform gland.*

The liver is attached to the anterior wall by a broad base, the peritoneum being reflected over the entire remaining surface. The

attaching fold of the peritoneum is frequently called the *suspensory ligament.* The peritoneum, or coelomic epithelium, can be dissected easily from the surface of the liver or the kidney and its extreme thinness and delicacy noted. It consists of a single layer of cells.

Most of the abdominal organs are suspended from the dorsal wall of the body cavity by delicate membraneous sheets, or *mesenteries.* Similar sheets between the organs are the *omenta.* The stomach is suspended by a *mesogaster,* which extends as a free fold along the body as far as the anterior mesenteric and lienogastric arteries. It encloses these, and is attached to the spleen, pancreas, stomach, and anterior end of the intestine.

The spleen is connected with the stomach by the *gastro-splenic omentum,* formed by an extension of the peritoneal coat of the stomach around the spleen. The liver is connected to the loop of the stomach by the *gastro-hepatic omentum* in which are the hepatic duct, portal vein, and hepatic artery. Near the stomach it is joined by a fold of the peritoneum from the duodenum, the *duodeno-hepatic omentum,* which also unites with the mesogaster.

The rectum and rectal gland are supported by a second median mesentary, the *mesorectum.*

In Eugaleus the mesentery extends the entire length of the abdominal cavity. It forms a broad sheet attached to the anterior end of the proximal limb of the stomach (mesogaster), to the anterior end of the intestine (mesentery proper), and to the rectum (mesorectum). There is not the reduction of the mesentery which there is in Squalus. The gonads are suspended from the lateral faces of the mesentery above the stomach and intestine. The gastro-hepatic omentum forms a broad sheet between the limbs of the stomach, joining the mesogaster dorsal to the stomach and the mesentery above the intestine.

A small division of the right lobe of the liver stands out between the main lobes. In this is located a long, narrow *gall-bladder.* Open the bladder by a longitudinal ventral incision. The opening into the *bile-duct* will be found near the anterior end of the bladder.

In Eugaleus, which does not possess such a median lobe, the gall-bladder lies hidden in the right lobe of the liver. It can be opened and explored, but the connection with the duct can usually be demonstrated only by scraping. Do this later.

The bile-duct passes along the dorsal side of the gall-bladder and the edge of the gastro-hepatic and duodeno-hepatic omenta to the junction of the duodenum and large intestine, where it opens into the alimentary canal. Trace its oblique course through the wall of the intestine. The bile duct and the collecting (hepatic) ducts of the liver will be traced in the liver at a later stage of the dissection.

The *pancreas* consists of two lobes; a slender lobe lying dorsal to and parallel with the stomach, and a flattened oval lobe lying upon the ventral surface of the duodenum, connected with the dorsal lobe by a slender bar of glandular tissue.

The *pancreatic duct* passes from the extreme right end of the duodenal lobe obliquely through the wall of the intestine, opening into the anterior end of the large intestine. Free the edge of the lobe from the peritoneum and follow the duct.

Open the proximal limb of the stomach by a ventral incision which shall not cut any large blood vessels. Wash out the interior. Observe the three coats of the stomach; the outer peritoneal, the middle muscular, and the inner mucous coats. In the anterior portion of the stomach the mucous coat projects in the form of large papillae (absent in Eugaleus). Posterior to these, observe the irregular folding of the mucous coat, depending upon the degree of contraction of the muscular coat.

The muscular coat consists of an outer circular and an inner longitudinal layer of muscle fibres. Separate the two layers from each other and from the mucous coat; observe the network of blood vessels between the longitudinal muscles and the mucosa.

Open the pyloric end of the stomach, continuing the cut through the pylorus into the intestine. Examine the coats as before, observing especially that an outer layer of longitudinal muscle fibres is frequently developed, and that the pyloric valve is formed by an increase in the thickness of the coat of circular fibres.

Cut through the wall of the large intestine along the right side from its anterior end to the rectum. Do not cut deeper than the thickness of the wall. Corresponding to the external markings, the mucous membrane projects internally in a spiral fold, known as the *spiral valve.* Separate the wall of the intestine from the edge of the spiral fold upon both sides of the longitudinal incision, exposing a considerable surface of the valve. Wash well, and observe the character of the valve, the direction of the folds, and the manner of the reversal of their direction which usually takes place in the posterior half of the valve.

Cut across the *rectal gland* at its middle. Observe the character of its tissues, and then insert a bristle into the central cavity of the gland and pass it into the rectum. Open the rectum and note the point of communication of the two organs.

URINARY AND REPRODUCTIVE ORGANS. The *kidneys* (*mesonephri, Wolffian bodies*), are slender bodies extending along the entire length of the dorsal wall of the abdomen. The posterior moiety of each is thicker and wider than the anterior, which appears to have largely lost the functions of excretion in adult dogfish. Notice the position of the kidneys outside the peritoneum.

THE MALE. The *teste*s are white bodies lying to the right and left of the oesophagus, dorsal to the anterior portion of the liver. Each is suspended by a fold of the peritoneum, the *mesorchium.* (The testes of Galeus are long bodies attached to the sides of the mesentery.)

Showing through the peritoneum, a much convoluted, white tube can be seen on the ventral surface of the kidney. This is the *mesonephric* or *Wolffian duct.* In young specimens it may be nearly straight, lying near the medial border of the kidney. In adult specimens it can be followed forward as far as the anterior end of the testis. While the Wolffian duct is the duct of the kidney, and is joined by tubules of the anterior part of the kidney, it is so modified in the male that its principal function is to serve as the duct of the testis, a *vas deferens.* The collecting tubules of the posterior part of the kidney join to form a *urinary duct* which is independent of the Wolffian duct. The posterior end of the Wolffian duct is straight and considerably expanded, forming a large *seminal vesicle.* The duct becomes more and more closely convoluted as it passes forward, and the kidney tissue overlying it diminishes. At the anterior end of the mesonephros the Wolffian duct forms a mass of tubules, the *epididymis.* Very small tubules, the *vasa efferentia,* pass from the anterior end of the testis to the epididymis. These are difficult for the student to distinguish.

Cut through the peritoneum along the outer side of one kidney. Then strip the peritoneum toward the inner border of the kidney. The urinary duct will usually be closely attached to the peritoneum and parallel with the Wolffian duct, but nearer the midline of the body. The urinary duct can be separated from the peritoneum by

a little careful work. Numerous small ducts pass from the kidney into the urinary duct.

Open the uro-genital papilla near its tip and extend the incision forward so as to open the sac connected with the base of the papilla. The pore at the tip of the papilla leads into a space within the papilla itself, the *uro-genital sinus,* which branches to the left and right in pouches which extend beyond the posterior ends of the vasa deferentia. These cornua of the uro-genital sinus are of variable length, and are often named sperm-sacs. In a mature male they may be found to be filled with sperm, as may also the seminal vesicles and the convoluted portion of the Wolffian duct. The openings of the vasa deferentia into the sinus are large and easily located. The urinary duct opens into the sinus by a separate pore just behind the opening of the vas deferens.

Cut open the seminal vesicle and part of the convoluted vas deferens. The space within is subdivided by transverse folds or lamellae extending from a longitudinal ridge.

No vasa efferentia can be distinguished in Eugaleus. The anterior extremities of the kidney and testis of each side come into close contact with each other and here the vasa efferentia pass from the testis to the vas deferens. The sperm-sac is a large blind pouch, one or two inches in length, leading out of the posterior end of the vas deferens, and directed forward along its side. The vas deferens of Eugaleus is not convoluted.

In the young specimens usually supplied to laboratories the vas deferens is straight and no seminal vesicle is developed. The vasa efferentia are more difficult to see; otherwise the relations of the urinary and genital organs are as in the adult.

The suspensory ligament of the liver is continued posteriorly along the midline of the ventral body-wall; the dorsal edge supports a funnel which opens into the abdominal cavity by a long, narrow mouth. From the anterior end of the funnel two narrow tubes pass to the right and left over the anterior surface of the liver. They end blindly in the tissues dorsal to the anterior end of the liver. These are vestiges of the Muellerian ducts (pronephric ducts) which form the oviducts of the females.

THE FEMALE. The ovaries are large, white bodies lying at the sides of the stomach, dorsal to the lobes of the liver. Each is covered by the peritoneum and suspended by a fold of the same, the *mesovarium.* Ova of various sizes may be felt in the tissue of the ovary, which should be exposed by dissection.

The ovaries of Eugaleus are long slender bodies lying on either side of the mesogaster, dorsal to the stomach and intestine. Their posterior portions are fused.

The *oviducts* (*Muellerian ducts*) are large tubes suspended from between the kidneys by a narrow peritoneal band. The posterior portion of the oviduct, where development of the eggs takes place, is considerably enlarged. Each oviduct opens separately into the cloaca by a pore at the side of the urinary papilla. Followed forward, the oviducts pass over the anterior surface of the liver and following a continuation of the suspensory ligament, bend around posteriorly and unite. At the point of union they open into the coelom by a common, large, funnel-shaped aperture, the *ostium tubae.*

Cut through the peritoneum along the outer side of one kidney. Then strip the peritoneum toward the inner side of the kidney. Numerous small excretory ducts will be seen joining the main *urinary duct* (*Wolffian duct, mesonephric duct*), which runs along the inner margin of the kidney. Make an incision in the side of

the urinary papilla to open the cavity within it, the *urinary sinus.* The connection of this with the pore at the tip of the papilla should be demonstrated. Extend the incision forward. The urinary sinus divides into right and left cornua which are of considerable size and lie dorsal to the oviducts. Trace the Wolffian duct to the urinary sinus and demonstrate its opening into the cornu anterior to the point where the two cornua unite.

In young specimens the ovaries are small, and the oviducts are narrow, white tubes lying along the medial margins of the kidneys.

Nephrostomes, short, segmentally arranged kidney tubules which open to the coelom by a funicular aperture, are found by a close examination along the medial border of each kidney. They should be observed carefully with the aid of a good dissecting lens. Learn the significance of these structures.

In the course of development two sets of nephridia (kidneys) are formed. The first (pronephros) develops just back of the head of the embryo, but does not persist in the adult. Its duct, known commonly as the Muellerian duct, develops into the functional oviduct of the female, but forms an apparently useless vestige in the male. The second kidney (mesonephros) develops behind the first and is the excretory organ of the adult. Its duct (frequently given the name of Wolffian duct) is the urinary duct in the female, but functions in the male chiefly as a sperm duct, and therefore is called the vas deferens. The collecting tubules of the posterior portion of the kidney of the male unite to form a urinary duct which opens into the Wolffian duct or the urogenital sinus.

RESPIRATORY ORGANS

Open the anterior gill-pouch of the left side by dorsal and ventral cuts extending from the angles of the cleft, but cutting only as far as is necessary to see the structures within the pouch. Upon the medial side the gill pouch opens into the pharynx by a dorso-ventral slit, guarded by projecting cartilagineous *gill-rakers,* which prevent particles of food from passing into the gill pouch with the respiratory current. On both the anterior and posterior wall of the pouch is a *demi-branch.* If the specimen is injected a large blood vessel can be seen through the skin in the inner border of the demibranch, and small vessels passing from this into the leaflets, where the interchange of gases between the water and blood takes place.

Open similarly each pouch of the same side, observing the number of the demi-branchs and their relation to the pouches.

Upon the anterior wall of the spiracle demonstrate a row of small vestigial gills; being supplied with arterial instead of venous blood they form what is termed a *pseudobranch.*

VASCULAR SYSTEM

HEART AND VENTRAL AORTA. Continue the longitudinal incision through the skin as far as the mandible.* Dissect away the sheet of muscles between the gill-pouches and the mandible, exposing a slender muscle which extends from the pectoral girdle to the middle of the mandible. The *thyroid gland* lies dorsal to the anterior end of this muscle, close against the mandible. (The thyroid of Eugaleus is a broad, flattened structure covering the anterior ends of the coracohyoideus muscles.) Carefully dissect out the muscles lying between the branchial pouches of the right and left sides.

*See footnote, p. 31.

In front of the pectoral girdle lies a thin walled sac, the *pericardial sac.* Open it by a median ventral incision. Remove about one-half inch of the middle of the pectoral girdle, being careful not to cut the thin-walled part of the heart lying dorsal to it. The *pericardial cavity* is a pear-shaped chamber containing the heart, and lined by the smooth *pericardium* which is morphologically equivalent to the peritoneum. At the anterior extremity of the chamber the pericardium is seen to be reflected backward over the surface of the heart, thus forming its smooth outer coat.

The *heart* may be considered as a bent tube, enlarged in certain regions to form the chambers. Anteriorly and ventrally is a short, thick-walled tube, the *conus arteriosus;* this leads out of the pericardial sac anteriorly, while posteriorly it opens into a large muscular chamber, the *ventricle.* Dorsal to the ventricle, and projecting on either side of it is the thin walled *auricle.* Dorsal to both ventricle and auricle is the extremely thin-walled *sinus venosus.* This is triangular in shape, the apex opening into the posterior side of the auricle, the base attached to the posterior wall of the pericardial cavity; the lateral angles are drawn out into the *ducti cuvierii,* which receive veins from the anterior and posterior parts of the body. From the conus arteriosus springs a smaller vessel, the *ventral aorta,* which passes forward between the gill pouches. Take note of the small arteries passing over the surface of the conus and along the inner ends of the gill pouches, and take care not to cut them or their branches in the subsequent dissection.

Two pairs of arteries leave the ventral aorta as it emerges from the pericardial sac. The aorta then passes forward some distance and finally divides into two branches which pass to either side. Follow the branches of the aorta outward on the left side and demonstrate their courses. The anterior branch quickly divides into two, the anterior of these passing along the base of the first demibranch. The posterior enters the septum between the first and second pouches, and supplies the second and third demibranchs. The middle branch of the aorta passes directly to the fourth and fifth demibranchs. The posterior branch divides almost as it leaves the aorta, its branches supplying the remaining demibranchs. There is considerable variation in this branch of the aorta. It usually divides as stated, but it frequently passes some distance toward the gills before dividing, and in a considerable number of cases two vessels arise directly from the aorta instead of one.

The arteries carrying blood from the ventral aorta to the gills are named the *afferent branchial arteries.* Observe the relation of these vessels to the gills.

VENOUS SYSTEM. All the blood of the body is conveyed to the sinus venosus. The sides of the sinus venosus are extended as large vessels, already referred to as the ducti cuvierii. Open the sinus and ducti by a transverse ventral incision. The ducti pass directly into the lateral veins. Near the middle of the posterior wall of the sinus is an aperture of varying size, the opening of the *hepatic sinus;* there are rarely two openings in Squalus, always two in Eugaleus. A large opening on the posterior wall of each ductus leads into the *posterior cardinal vein.* On the anterior wall of the ductus, near the sinus venosus, is a small aperture, that of the *inferior jugular vein.* Lateral to this is frequently a somewhat larger opening of the *anterior cardinal vein.* This is absent, however, in

the majority of specimens; the anterior cardinals opening into the anterior ends of the posterior cardinals in about six out of ten cases.

A large cavity, the *hepatic sinus*, exists in the anterior end of the liver just posterior to the suspensory ligament. Cut into the liver at this point until the sinus is found, open it, and observe the large *hepatic veins* bringing blood into it from the liver, as well as its communication with the sinus venosus.

Trace all veins by passing a flexible probe or guarded bristle along them and then opening the vein with the probe as a guide. All smaller vessels emptying into those described should be noted.

The *lateral veins* pass forward to the posterior edge of the pectoral girdle, bend sharply dorsad, and enter the lateral extremities of the ducti cuvierii. Open a lateral vein near the anterior end and trace it toward the heart. The right and left lateral veins are joined by a vein passing along the ventral bar of the pectoral girdle. Open the lateral veins at a point about two inches in front of the pelvic girdle and trace the veins backward as far as they can be followed. The blood from the pelvic fins enters the lateral vein through the *femoral vein*. The lateral veins finally unite back of the cloaca.

Just before the lateral vein enters the ductus cuvierius it is joined by a large *coracoid vein* which runs dorsad and posteriorly along the posterior edge of the pectoral arch. Follow its course. It receives a good-sized *pectoral* vein from the pectoral fin, and sometimes several smaller veins from the same region. Traced dorsad it is found to open into a large blood sinus above the liver and oesophagus, the *cardinal sinus*.

In Eugaleus this connecting vein between the lateral vein and the cardinal sinus is wanting, the pectoral vein opening directly into the lateral.

The *ventral cutaneous vein*, which runs along the ventral midline of the body wall, should be followed; anteriorly it joins the vessel uniting the two laterals; posteriorly it divides at the pelvic arch and anastomoses with the laterals.

Pass a bristle from the sinus venosus into one of the *posterior cardinal veins* and trace the vein backward between the kidneys as far as possible. Open both posterior cardinals in this way, washing them out and observing that they receive blood from the kidneys by a series of *renal veins*, and that they are separate in their posterior parts, but communicate with each other anteriorly, where they are greatly expanded; the communicating portions and coincident enlargement forming the *cardinal sinus*. The anterior portion of the cardinal vein receives *ovarian* or *spermatic veins* from the female or male gonad, *anterior oviducal veins* from the anterior part of the oviduct, and segmental veins from the corresponding region of the body wall. There sometimes is more than a single opening from the posterior cardinal vein into the cuvierian duct.

Cut across the tail an inch behind the cloaca. Two vessels lie in the cartilaginous arch below the centra of the vertebrae; the dorsal of the two is the *caudal artery*, the ventral one is the *caudal vein*. Follow the vein forward. Dorsal to the cloaca it divides into two, which should be followed along the dorsal surfaces of the kidneys. These are the *renal portal veins*, conveying blood to the kidneys. Besides collecting the blood of the tail the renal portals also receive the *posterior oviducal* and *segmental veins*. They pass into the capillaries of the kidneys.

The *inferior jugular vein* opens into the medial end of the cuvierian duct. Trace it forward along the ventral ends of the gill-pouches; it receives vessels from the arches and finally joins the *hyoidean*

veins which follow the hyoid arch. At the outer end of the cuvierian duct there is often a small opening on the anterior wall opposite the mouth of the posterior cardinal vein. This leads into the *anterior cardinal vein.* As mentioned before, in a slight majority of the cases examined, the anterior cardinal vein opens into the posterior cardinal vein, not directly into the cuvierian duct. If possible, pass a bristle into the anterior cardinal. To follow the vein, and usually this is the best way to find it, make a vertical longitudinal incision upon the dorsal side of the neck, between the gill pouches and the mass of muscle lying beside the vertebral column. This will open the anterior cardinal, which is considerably expanded in this region, and it may be traced from this point toward the heart and the head. The anterior cardinal narrows suddenly in front of the anterior gill pouch, and leads downward to the orbit, where it expands into the *orbital sinus* surrounding the eyeball and its muscles. Trace the anterior cardinal only as far as the opening into the orbital sinus at this time. Veins from the anterior portion of the head and from the brain can be followed when the dissection of the eye is undertaken.

Just back of the spiracle the anterior cardinal receives the *hyoidean vein,* which passes ventrad along the base of the first demibranch and unites with the hyoidean of the opposite side. Ventrally, it also communicates with the inferior jugular vein.

The principal veins of the body have now been dissected with the exception of the *hepatic portal vein,* which it is better to trace after the arteries of the digestive tract have been studied.

The efferent branchial arteries and dorsal aorta. Commencing at the mouth, cut through the floor of the pharynx close to the left side of the ventral aorta and the heart. The cut should leave the gill arches uninjured, and may be continued into the oesophagus.

Examine the interior of the mouth and pharynx, observing particularly the form and arrangement of the teeth, the spiracular and branchial clefts, the gill-rakers, and the character of the mucous coat of the pharynx.

Remove the skin from the roof of the pharynx. This exposes four pairs of *efferent branchial arteries* bringing blood from the gills and uniting in pairs to form the *dorsal aorta.* Follow each vessel of the left side out to its gill-cleft. At the dorsal end of the gill-cleft it divides into a large posterior and small anterior branch. These respectively pass along the posterior and anterior demibranchs of the gill pouch, receiving fine branches from the gill lamellae, and finally unite again at the ventral end of the gill-pouch. Thus a complete loop is formed around the branchial cleft. The posterior branch of each efferent artery and the anterior branch of the succeeding one are united by several short vessels. The efferent artery of the last demibranch possesses only these connections with the branch next anterior to it, and none with the aorta directly. From the ventral ends of the efferent loops small vessels pass toward the mid-line to unite with a longitudinal artery, the *hypobranchial artery,* which will be traced farther a little later in the dissection.

In Eugaleus the dorsal aorta extends forward beyond the union of the first pair of efferent branchials and then divides into small right and left branches which pass forward and outward to unite with the common carotid arteries.

A *common carotid artery* leaves the dorsal end of each anterior efferent branchial loop, passing forward and inward. At the level of the spiracles it divides into *external* and *internal carotids;* the internal carotid unites with its fellow of the opposite side and enters the skull. The external carotid arteries run outward and forward

around the eyes and are distributed to the regions of the mandible and snout. Do not, at present, trace them beyond the posterior edge of the eye.

Another vessel arises from the middle of the anterior side of the first efferent branchial loop and runs forward to the spiracle, where it ends in the capillaries of the pseudobranch. This is the *afferent hyoidean artery.* The term pseudobranch is used for the branchial lamellae of the spiracle rather than demibranch because of the arterial blood supply of this organ.

Immediately after uniting the internal carotids divide and diverge, forming an X-shaped figure. Each anterior limb of the X again divides into two branches. The lateral branch passes to the ventral surface of the skull; it presently gives off an anterior twig (*ophthalmic artery*) which enters the eye. It then passes on as the *efferent hyoidean artery* to the pseudobranch. The inner of the two branchs mentioned above passes on as the *internal carotid, sensu strictu,* and is distributed to the brain.

If the dissection is made with care, the branches of the internal carotid can all be found without cutting any important nerves. The branches passing to the eye and brain are best traced to their terminations in connection with the dissection of the nervous system.

Near the union of the first pair of efferent branchial arteries a small *posterior vertebral artery* arises from each, and runs anteriorly along the vertebral column.

Near the divisions of the common carotids two *anterior vertebral arteries* arise from these vessels and pass posteriorly, often anastomosing with the posterior vertebral arteries. These vertebral arteries are vestiges of the former anterior part of the dorsal aorta (compare with Eugaleus, in which the dorsal aorta sends forward two vessels which join the common carotids).

An *oesophageal artery* springs from the second efferent branchial, and passes back until it enters the wall of the oesophagus. It also gives off nutrient branches to the second, third, and fourth gill pouches. The nutrient artery of the first gill pouch arises directly from the first efferent branchial.

Near the point at which the fourth pair of efferent branchials join the aorta, two small *subclavian arteries* leave the aorta and pass into the pectoral fins. There is some variation in regard to the point of origin of these vessels; it may be either in front of or behind the junction of the fourth efferent branchials with the aorta.

The *hypobranchial artery* passes along the ventral ends of the gill pouches. It is either connected with the efferent branchial loops by short branches, or is formed, in part at least, by short vessels connecting these loops. The hypobranchials are important nutrient vessels, supplying the gill pouches and the muscles of the throat and the oesophagus by means of numerous small arteries; from the hypobranchials also arise small *posterior coronary arteries* which pass to the ventral and posterior walls of the pericardium and the sinus venosus, and larger *anterior coronary arteries* supplying the ventricle and conus arteriosus. The hypobranchials can frequently be followed along the dorsal side of the pericardium and then outward to junctions with the subclavian arteries.

The *coeliac artery* (*coeliac axis*) arises from the aorta just back of the subclavians. Passing posteriorly and ventrad close to the right side of the stomach and reaching the gastro-hepatic omentum, it divides into two branches, the *gastro-hepatic* and *anterior intestinal arteries.* The first gives off a small *hepatic artery* to the liver

and a large *gastric artery* to the cardiac limb of the stomach. The *anterior intestinal artery* supplies the pyloric limb of the stomach, the pancreas, duodenum, and right side of the large intestine.

Small *genital arteries*, supplying the reproductive glands, arise from the coeliac near its origin. (In Eugaleus the genital arteries arise from the anterior and posterior mesenteric arteries.)

At about the middle of the abdominal cavity two arteries arise close together from the aorta. The anterior of the two is the *anterior mesenteric artery;* it passes to the left side of the large intestine and its branches anastomose more or less with those of the anterior intestinal artery. The posterior vessel is the *lieno-gastric;* it goes to the spleen, pancreas, and loop of the stomach.

The *posterior mesenteric artery* leaves the aorta a little distance back of the lienogastric and passes to the rectal gland, rectum, and cloaca.

Free the kidney from the body wall along its outer edge and turn it up so as to expose its dorsal surface. Observe the numerous *parietal* arteries (going to the body wall) and *renal arteries* (to the kidney), which spring from the dorsal aorta. Branches of the parietals also pass into the kidney.

A pair of small *iliac arteries* pass into the pelvic fins.

Oviducal arteries, one or several on each side, arise from the aorta behind the coeliac artery and pass to the oviduct. Their size varies largely with the development and physiological condition of the oviduct.

The aorta is continued in the tail as the *caudal artery*.

DISSECTION OF THE HEART. Remove the heart together with the ventral aorta from the body and fasten it, dorsal side up, under water. Open the sinus venosus with scissors, wash it out, and observe the vertical slit-like opening into the auricle and the two membraneous valves which guard it.

Continue the cut through the *sinu-auricular aperture* along the median dorsal line of the auricle; observe the thin walls of the auricle and their strengthening by an irregular mesh of muscles, the *musculi pectinati;* the shape and position of the *auriculo-ventricular aperture;* the flaps of the *auriculo-ventricular valve*. Press upon the sides of the ventricle and, if possible, observe the mode of action of the valve.

Cut across the ventricle from the auriculo-ventricular aperture. Carry another incision from this along the dorsal side of the conus arteriosus. Observe the small size of the cavity of the ventricle, the thickness of its walls, and the projecting network of muscles, the *columnae carneae*, some of which are attached to the edges of the auriculo-ventricular valves.

In the conus arteriosus observe the rows of three pocket-like valves each around the proximal end (*semilunar valves*), and a single row of three similar but larger valves at the junction of the conus and ventral aorta. There is some variability in the number of rows of valves in the conus of Squalus; there are always three rows of three valves each in that of Eugaleus.

In the aorta notice the apertures without valves which lead into the afferent branchial vessels.

HEPATIC PORTAL SYSTEM. The *hepatic portal vein* is the large vein entering the liver alongside the hepatic artery and bile duct. It receives branches from the stomach, pancreas, spleen, intestine, and rectal gland.

At the surface of the liver it divides into two branches, which enter the two lobes of this organ. Within the liver the hepatic portal veins branch until a capillary sytem is formed from which the blood is collected by the hepatic veins and carried into the sinus venosus.

In general, the branches of origin of the hepatic portal vein follow closely the arteries of the digestive organs. Trace the following parts of the system: A *posterior intestinal vein,* from the rectal gland and rectum, the large intestine and spiral valve, across to the end of the pancreas, along the pancreas to the hepatic portal vein; an *anterior intestinal vein,* from the large intestine and spiral valve, along the duodenal lobe of the pancreas; *gastric, duodenal,* and *pyloric veins* joining the veins already traced; a *splenic vein* joining the posterior intestinal vein.

The liver, with the bile duct, may now be removed from the body if it is desired to trace the bile duct into the bladder or to trace the hepatic ducts. This can be done best by gently scraping away the soft liver tissue until the bladder and ducts are exposed.

THE NERVOUS SYSTEM.

Only the head and anterior part of the trunk will be required for the dissection of the nervous system. Cut across the body back of the pectoral fins; the posterior part of the body will not be required further unless it is desired to study the muscles and skeleton.

The manner of dissecting the brain depends somewhat upon the specimens at the disposal of the student. If a large head is to be used especially for the dissection of the cranial nerves, only the brain, eye and ear need be studied in the present specimen. But in most cases it will be found best for the student to dissect the first dogfish as thoroughly as possible, working out the cranial nerves as well as the brain, and reserving the second head for a thorough review of the entire nervous system. Chapter III of Herrick and Crosby's "Laboratory Outline of Neurology" should be used in connection with such a review.

If a line be drawn over the dorsal surface of the head connecting the two spiracles, two small pores will be found near the middle. These are the external apertures of the ducti lymphatici. Cut carefully through the skin in a small circle around the pores, and remove the skin from the remainder of the dorsal surface of the skull without disturbing the small section containing the pores. The latter part should now be lifted gently; beneath it will be seen two delicate tubes passing from the pores to apertures in a depression of the skull below them. These tubes are the *ducti endolymphatici,* through which a passage exists between the internal ear and the exterior. As they cannot be preserved in the subsequent dissection, the pores by which they pass through the skull to the internal ear should be found now, and a memorandum-sketch made of the ducts themselves.

DORSAL SURFACE OF THE BRAIN. The roof of the skull should be removed from over the brain. Use a sharp scalpel and take very thin slices of cartilage. Do not cut beyond the brain at the sides. No attempt should be made at this time to expose more than the dorsal surface of the brain.

Above the anterior end of the brain there is a small median foramen through the skull, the *epiphysial foramen.* A strand of tissue, the *epiphysis,* leading from this to the surface of the brain, should be carefully observed and retained. The cartilage should

also be cut away from above the portion of the spinal cord next the skull. Gently wash away any coagulated lymph.

The brain and spinal cord are invested by two membranes (*meninges*). The tough *dura mater* lines the cavity in which they lie, clinging closely to the cartilage; in fact it forms the perichondrium of the internal surface of the cranium. The *pia mater* envelops closely the brain and cord, and contains numerous blood vessels. Between the two is the *arachnoid space*, traversed by occasional fine threads of connective tissue and filled with lymph.

As the spinal cord passes forward into the skull it enlarges and merges with the posterior portion of the brain, the *medulla oblongata* (*myelencephalon*). The roof of the medulla is extremely thin, and is broken if the cartilage has not been removed with extreme care, exposing a cavity within, the *fourth ventricle.*

In front of the medulla, and overlapping its anterior extremity, is a large oval organ, the *cerebellum* (*metencephalon*). Ventral to the cerebellum, each side of the medulla is expanded in an ear-shaped lobe, the *corpus restiformis.* Anteriorly, the cerebellum overlaps a pair of rounded lobes, the *optic lobes*, which together form the dorsal portion of the *midbrain* (*mesencephalon*).

In front of the optic lobes are two slightly larger lobes united in their posterior portions but separated anteriorly, the *cerebral lobes* or *hemispheres.* Together they constitute the *prosencephalon.* (The prosencephalon is not divided in Eugaleus.) Between the mesencephalon and the prosencephalon is a depressed region belonging to the brain-stem, the *diencephalon* (*thalamencephalon*), from which the epiphysis arises. The roof of the diencephalon also is very thin and is frequently broken during the exposure of the brain. The cavity seen within the diencephalon is the *third ventricle.*

Stalked bodies arising from the antero-lateral angles of the cerebral hemispheres are the *olfactory lobes.* The portion of the brain including the cerebral hemispheres and the olfactory lobes constitutes the *telencephalon.*

Dissection of the internal ear. The structures composing this organ lie in the projecting cartilage at the side of the medulla (auditory capsule). Remove the cartilage of the auditory capsule in thin slices and bit by bit, following the ductus endolymphaticus to the membraneous labyrinth. Dissect away the surrounding cartilage leaving the membraneous canals in place, until the entire labyrinth is exposed. The *membraneous labyrinth* consists of a large central sac (*utriculo-saccular chamber*) into which the endolymphatic duct opens, and three membraneous tubes (*semicircular canals*) external to the chamber but communicating with it in various ways. Two, one anterior and the other posterior to the sacculus, lie in a nearly vertical plane (*anterior and posterior semicircular canals*); one is external to the sacculus and lies in a nearly horizontal plane (*horizontal or external semicircular canal*). At the ventral ends of the vertical canals are nearly spherical enlargements called *ampullae.* The ampulla of the horizontal canal is at its anterior end. The dorsal ends of the vertical canals open near each other into the upper part of the utriculo-sacculus. The ventral extremity of the anterior vertical canal and the anterior extremity of the horizontal canal open beside each other into an anterior projection of the sacculus. The ventral extremity of the posterior vertical canal opens into the posterior and lower part of the sacculus. The posterior extremity of the horizonal canal opens

into the posterior side of the sacculus. During life the utric sacculus and the semicircular canals are filled with a lymph fluid, and the sacculus contains a large calcerous ear-stone (*ótoli* which is usually dissolved by the formalin used in preserving dogfish.

Whitish patches of thickened sensory epithelium may be seer the ampullae (*cristate acusticae*) and in the utriculo-saccular ch ber (*maculae acusticae*). Branches of the eighth nerve can be lowed to all these areas.

A projection of the ventral wall of the utriculo-sacculus is *lagena*, the rudiment from which the cochlea of higher anin developed. It also contains a macula acustica.

External features of the eye. Observe the transpa cornea covering the external surface of the eye; the dark ring the iris; the central opening in the iris, the pupil; the conjur val sac surrounding the external half of the eyeball. Cut a sufficient of the upper wall of the cartilaginous orbit to expose eyeball and its muscles. Note the considerable amount of soft nective tissue around the eye and explore the orbital sinus (p. Take notice of the following nerves, in order to ensure their pre vation until the time comes to trace them more completely. A la nerve crossing the medial side of the orbit, the superficial opht mic; a nerve leaving the cranium opposite the optic lobe, pass under the superficial ophthalmic to the anterior muscle of the ball, the trochlear; several long ciliary nerves passing to the ball; several other nerves visible in the deep angle of the orbit.

Six muscles move the eye. Four of these arise close toge at the deep postero-medial angle of the orbit. Diverging, they inserted upon four sides of the eyeball, and from the positior their insertions are named the *superior*, *posterior*, *inferior*, *anterior recti*. Two muscles arise from the antero-medial angl the orbit, the *superior and inferior oblique muscles*.

Between the recti muscles can be seen a mushroom-shaped s of cartilage, the *ophthalmic peduncle;* the eyeball rests agains expanded end. (There is no peduncle in Eugaleus.)

The cranial nerves. The cranial nerves are twelve pair nerves arising from the brain, and thus distinguished from the sp nerves which arise from the sides of the spinal cord. They are tributed chiefly to the head and neck, though branches of the va nerve go to the viscera and to the sense organs of the lateral Since the nerves are all paired, the distribution of both nerves pair being alike, the descriptions will mention but one nerve pair. As the cranial nerves are traced dissect away the sides of cranium down to the foramina penetrated by the nerves, and fol each nerve from its origin on the brain to the parts innervated b Features of the dissection which are not found in tracing the n of one side should be sought on the other side.

The *olfactory nerve*. The anterior surface of the olfactory fills a large foramen in the anterior wall of the cranium an pressed closely against the posterior surface of the nasal sac. merous small nerves, collectively forming the olfactory nerve, a from the anterior face of the lobe, penetrate the membraneous of the olfactory organ, and are distributed to its highly folded face.

The *terminal nerve*, *Nervus terminalis*, is a slender nerve ning along the medial surface of the stalk of the olfactory l Follow it backward to its origin on the anterior surface of the c

bral hemisphere, deep in the median fissure (in Eugaleus on the ventral surface). Trace it forward over the dorsal surface of the olfactory lobe to where it enters the nasal sac. The terminal nerve is a true cranial nerve which has escaped notice until recent years. It is associated with the olfactory nerve in vertebrates generally from fishes to men. The fibres of the terminal nerve remain distinct from those of the olfactory nerve, both in the olfactory organ and in the brain. Its function is unknown. There is still a division of opinion among authorities as to whether the terminal nerve should be considered to be a distinct cranial nerve, or a portion of the olfactory nerve.

The *optic nerve* can be seen at the bottom of the orbit between the eye and the skull, nearly under the superior oblique muscle. It arises from the ventral side of the diencephalon, passes outward, penetrates the orbit at its infero-medial angle, and continues directly outward to the eyeball.

The *trochlear nerve*, or *patheticus*, penetrates the wall of the orbit opposite the optic lobe. Follow it back to its origin from the dorsal surface of the brain in the depression between the optic lobes and the cerebellum. Then follow it from the skull to the superior oblique muscle, which it innervates.

The *oculo-motor nerve* arises from the ventral surface of the midbrain, passes outward, and penetrates the orbit on a level with and just anterior to the origins of the recti muscles. It divides immediately into three parts; two pass to the anterior and superior recti respectively, while the third passes downward along the posterior surface of the eyeball to the inferior rectus and inferior oblique muscles. In tracing this nerve the palatine process of the upper jaw will be seen projecting from below into the orbit.

The *trigeminal, facial, and auditory nerves* spring from the side of the medulla below the corpus restiformis. The roots, and some of the branches, of the trigeminal and facial nerves are so mingled as to be indistinguishable except by special neurological technique. The common root of the trigeminal and facial nerves shows a partial division into a dorsal and a ventral portion; the dorsal portion belongs to the facial nerve, while the ventral root is mixed. The root of the auditory nerve lies close behind the trigeminal-facial root, but can be distinguished fairly well. Both the trigeminal and facial nerves divide into several trunks, namely:

Trigeminal	Facial
superficial ophthalmic	superficial ophthalmic
deep ophthalmic	buccal
maxillary	otic
mandibular	hyomandibular

The *superficial ophthalmic* trunks of the two unite in a single nerve which passes along the inner wall of the orbit above the muscles of the eye to a foramen in the antero-medial angle of the orbit, through which it passes to the dorsal surface of the snout. The superficial ophthalmic nerve of Squalus is composed almost entirely of fibres of the facial nerve. The superficial ophthalmic trunk of the trigeminal gives rise to several small nerves leaving the common trunk near its origin and passing to the skin above the eye. The superficial ophthalmic trunk of the facial, nearly the whole of the common nerve, branches profusely to supply the sensory organs of the dorsal and lateral surfaces of the snout.

The superficial ophthalmic of Eugaleus rises from the dorsal part of the trigemino-facial root and leaves the cranium by a separate foramen above and anterior to the roots of the recti muscles.

Directly under the origin of the superficial ophthalmic will be found a comparatively slender nerve, which passes between the superior and posterior rectus muscles, and forward along the medial surface of the eyeball; it penetrates the anterior wall of the orbit by a separate foramen, and emerges under the superficial ophthalmic. It is distributed to the skin of the dorsal and lateral surfaces of the snout. This is the *deep ophthalmic* (*ophthalmicus profundus*) of the trigeminal nerve. A slender branch (*posterior ciliary nerve*) passes from the deep ophthalmic near its origin to the posterior surface of the eyeball. Farther forward the same trunk gives off an *anterior ciliary* nerve to the anterior part of the eyeball.

A large nerve which crosses the floor of the orbit, beneath the eyeball, consists of the *maxillary* trunk of the trigeminal and the *buccal* trunk of the facial nerve. These remain associated, even into the small branches. Near the anterior margin of the orbit the maxillary-buccal trunk divides into three parts; the smallest and outer one passes to the surface lateral and anterior to the eye. The other two dip downward and pass in front of the jaw to the ventral surface of the snout. Reflect the skin of the ventral surface of the snout, and by dissection expose these nerves as they emerge from the orbit. The larger branch runs forward close to the median line of the snout, giving off numerous twigs; the other, which appears to be a pure trigeminal branch, is distributed near the angle of the mouth. The fibres of the maxillary trunk supply the skin, while those of the buccal go to the canal organs and ampullae of Lorenzini.

The *mandibular* trunk of the trigeminal nerve arises beneath and behind the maxillary. It passes outward in front of the levator maxillae superioris muscle, sending a few twigs into this muscle, and turns downward over the palato-quadrate cartilage. It divides here, one part entering the adductor mandibularis muscle, the other passing downward along the edge of the mandible, innervating the skin of the lower jaw and the first ventral superficial constrictor muscle.

The mandibular and maxillary-buccal trunks of Eugaleus are united until they approach the edge of the orbit, and the palatine branch is much larger; otherwise the trigemino-facial branches are much as in Squalus.

The *hyomandibular* trunk of the facial nerve can be found just beneath the skin behind and close to the spiracle. From here it can be followed back to the brain. It arises from the ventral part of the trigemino-facial root, emerging from the cranium through the hyomandibular canal. It divides into a number of branches just beyond the spiracle:

1. The *external mandibular* branch consists of two portions, a small anterior nerve extending antero-ventrally to the canals above and below the angle of the mouth, and a larger nerve which passes laterally and suddenly breaks up into a brush of twigs which innervate the hyoidean group of ampullae.

2. The *internal mandibular* branch arises at about the same level as the external mandibular, but under it, passes inward around the edge of the hyoid cartilage, under the adductor mandibularis muscle, and then forward along the mandibular cartilage.

3. The *hyoid* branch separates from the hyomandibular trunk at about the same level as the preceding nerves, and then passes, deep in the tissues, around the angle of the jaw to the ventral side where it is distributed to the superficial constrictor muscles. Several nerves pass from the hyomandibular trunk and the hyoid branch to the dorsal superficial constrictors.

4. The *palatine* branch springs from the base of the hyomandibular trunk inside the hyomandibular canal. It passes outward and forward, dividing into numerous branches which innervate the mucous membranes of the mouth. It can be traced completely later.

One or more small nerves proceeding to the pseudobranch and anterior wall of the spiracle arise near the point of origin of the palatine branch.

The *otic nerve*, passing from the root of the facial nerve to the postorbital canal, is not likely to be found in this dissection.

Observe the enlargement near the base of the hyomandibular trunk, and within the cartilaginous canal, the *geniculate ganglion*. The *gasserian ganglion*, a component of the trigeminal nerve, lies in the ventral portion of the trigeminal-facial root, and can now be located.

The *auditory nerve* arises close behind the ventral division of the trigemino-facial root. The root of the auditory nerve encloses a large *auditory ganglion*. A *vestibular nerve* arises from the anterior end of the auditory ganglion and passes into the ear capsule, innervating the upper part of the utriculo-sacculus and the ampullae of the anterior and horizontal canals. From the posterior part of the ganglion nerves pass to the ventral part of the sacculus and the ampulla of the posterior canal. Trace these branches as thoroughly as possible.

The *abducens nerve* emerges from the cranium under and close to the origin of the posterior rectus muscle, into which muscle it enters. To expose this nerve the trigeminal, facial and auditory nerves must be lifted and cut as they pass through the wall of the cranium. It can be traced obliquely backward and inward, through a long canal, to its origin near the mid-line of the ventral surface of the medulla.

The *glossopharyngeal nerve* passes through the base of the ear capsule from the side of the medulla to the upper end of the first branchial pouch. A ganglionic enlargement is found near where it emerges from the cartilage. Outside the cranium the glossopharyngeal divides into a *pretrematic branch*, passing down in front of the first gill pouch, and a *posttrematic branch* running behind the pouch. The pretrematic branch quickly sends off a *pharyngeal nerve* which runs antero-ventrally to the roof of the pharynx. The pretrematic and posttrematic branches can be followed along the gill-arch to the ventral side of the pharynx. A fourth branch of the glossopharyngeal, the *supratemporal*, springs from the dorsal side of the ganglion; passing through the ear capsule it runs to the dorsal surface of the head, where it is distributed to the sense organs of a short section of the lateral line canal. This small nerve can be demonstrated by carefully separating the muscles and perichondrium from the posterior surface of the auditory capsule.

The *vagus nerve* (or *pneumogastric*) arises by an extensive series of roots from the side of the medulla. An easily distinguished ribbon-like portion of the root, the *lateral line root*, runs forward as far as the root of the glossopharyngeal. Note the canal by which the vagus leaves the cranium, and trace the nerve along the inner side of the anterior cardinal vein.

The principal branches of the vagus are:

1. The *supratemporal* branch, a small nerve running dorsal through the posterior part of the ear capsule to the lateral line canal and other sense organs of the head. It will be found near the supratemporal branch of the glossopharyngeal.

2. The *lateral line branch*, a large nerve which separates from the trunk of the vagus just outside the cranium and runs backward through the muscles, parallel to the vertebral column on a level with the lateral line. It sends off numerous small twigs to the sense organs of the lateral line canal.

3. Four *branchial* nerves, which can be seen through the floor of the anterior cardinal vein, leave the outer side of the vagus trunk. Each divides into a pretrematic and posttrematic branch; a pharyngeal branch, the last of which is the largest, arises from each posttrematic.

4. Beyond the branchial nerves the remainder of the vagus passes backward as the *intestinal* or *visceral* trunk, to the end of the pharynx, where it divides into a number of branches which are distributed chiefly to the wall of the stomach. Near the point of this last division the vagus is crossed by the hypobranchial nerve, which should be noted and preserved.

The *occipital nerve* penetrates the lateral wall of the cranium close behind the root of the vagus and enters the canal of the vagus, along which it passes. On emerging, it sends small branches to the nearby muscle, while the principal portion runs on to join the hypobranchial nerve. The occipital nerve will be found to arise from the ventral surface of the medulla, below and behind the root of the vagus, by two or more distinctly separated roots, which may represent distinct nerves.

Spinal nerves. The spinal nerves are those nerves which arise from the sides of the spinal cord. They differ from the cranial nerves not only in their origin outside the cranium, but also in that each spinal nerve arises by two roots which spring from the spinal cord near the dorsal and ventral surfaces. Each root passes through a foramen in the cartilaginous wall of the neural canal, the ventral a little anterior to the dorsal, after which they unite to form the spinal nerve. Between the junction of the roots and its foramen the dorsal root contains a mass of ganglion cells, which cause an enlargement known as the *dorsal root ganglion*. The typical course of a spinal nerve is around the body to the ventral surface, giving off branches to the muscles and skin of its segment. A short distance from the vertebral column the spinal nerves lie just outside the peritoneum, through which many of them can be seen and followed to about the level of the lateral vein. At this point they pass outward into the muscles of the body wall. To dissect any of the spinal nerves make a longitudinal incision along the lateral line and separate the dorsal muscle mass from the lateral muscles for some distance. The dorsal muscles can then be pressed toward the vertebral column and dissected away from the peritoneum. The spinal nerves, lying against the peritoneum, will be exposed and can be followed easily, first to their roots, next ventrally.

The *hypobranchial nerve*, to which attention was called at the point where it crosses the vagus, is formed by the union of the principal branches of the occipital and first two spinal nerves. The third spinal nerve receives a branch from the second, and itself accompanies the hypobranchial nerve closely without actually becoming a part of it. The union of nerves thus formed is known as a plexus. After crossing the vagus the hypobranchial nerve forks, one division passing medial to, the other lateral to the anterior cardinal vein; both run ventrally, following the last gill arch, and reunite on the lateral wall of the pericardium, forming a trunk

which runs forward. At the anterior end of the pericardium this divides into a dorsal and a ventral branch which innervate the surrounding muscles. The hypobranchial nerve innervates the skin of the region immediately in front of the pectoral girdle, and the coraco-arcualis communis, coracomandibularis, coracohyoideus, and coracobranchialis muscles.

The third, fourth, fifth and sixth spinal nerves pass backward and ventrad till they reach the level of the articulation of the pectoral fin with the girdle. Here they join to form a simple *brachial plexus*, from which arise branches proceeding to the musculature of the dorsal and ventral faces of the fin. The seventh to eleventh spinal nerves pass downward to the level of the fin, and then branch, one portion entering the muscles of the ventral body wall, while the other passes into the depressor muscles of the fin.

The pelvic fin is innervated by eight or nine spinal nerves which pass backward and downward along the medial edge of the septum between the myomeres, entering the dorsal side of the fin along its axis. No plexus is formed.

Olfactory organ (nasal sac). Dissect away the skin and other tissues around the nostril so as to expose completely the olfactory organ; this will be found to be a dark-colored, nearly spherical mass, of half the diameter of the eye, firmly attached at its base. By cutting away the cartilage dorsal to the nasal sac its base will be exposed, and the olfactory bulb will be shown to be closely adherent to a considerable part of the postero-dorsal surface of the organ. Numerous short nerves can be demonstrated to pass from the olfactory bulb into the olfactory organ; all these nerves together are considered as the first cranial or olfactory nerve. Remove the olfactory organ from the head; divide it by a median longitudinal cut; observe the arrangement and structure of its double series of internal folds (lamellae), and the complete median septum.

Ventral surface of the brain. Cut the cord in two some distance back of the brain. Cut all cranial nerves just inside the cranium and carefully lift the brain out. Parts of the ventral portion of the brain lie in a recess beneath the mesencephalon and must be disengaged very gently.

Identify and examine the ventral parts of the brain. Note the considerable lateral compression of the mesencephalon. The optic nerves cross beneath the diencephalon, forming the *optic chiasma.* From the sides of the chiasma slightly elevated *optic tracts*, formed by the fibres of the optic nerves, can be traced into the optic lobes.

Back of the optic chiasma the projecting ventral portion of the diencephalon forms the *hypothalamus.* The posterior lobe of this structure is the *hypophysis* or *pituitary body.*

The oculomotor nerves emerge over the posterior end of the hypothalamus.

The ventral portion of the mesencephalon is formed by the *cerebral peduncles* (*crura cerebri*), columns of fibres passing between the myelencephalon and telencephalon.

The abducens nerves arise on the ventral surface of the myelencephalon near the midline and just back of a line connecting the roots of the auditory nerves.

The *internal carotid arteries* reach the brain at the sides of the hypothalamus. Branches are sent upward and forward over the surface of the brain. Anastomoses between the vessels of the opposite sides are formed anterior to the optic chiasma. The main branches of the carotids pass backward along the sides of the hypo-

thalamus and unite behind this organ. The median artery thus formed runs along the ventral surface of the myelencephalon and the spinal cord. Numerous transverse vessels are given off to the myelencephalon.

Identify the roots of the remaining cranial nerves.

CAVITIES OF THE BRAIN. Divide the brain into exactly equal halves by a vertical longitudinal cut.

Each lobe of the prosencephalon contains a large cavity. These are the *prosocoels.* They are commonly known either as the lateral ventricles, or the left cavity as the first ventricle and the right as the second ventricle. The prosocoels are continued into the olfactory lobes, these portions being known as rhinocoels.

The *thalamocoel* is the cavity within the diencephalon, often called the third ventricle. The prosocoels communicate with the thalamocoel by lateral openings, the *foramina of Monro.* The roof of the thalamocoel is very thin and is non-nervous; it is frequently torn during the early dissection. Where the lobes of the prosencephalon meet the dorsal wall of the diencephalon this thin roof is pushed into the prosocoels, carrying with it the pia mater and its blood vessels, and thus forms vascular ingrowths known as the *choroid plexi.* The thalamocoel continues above into the epiphysis and below into the hypothalamus.

The *myelocoel* is the large cavity of the myelencephalon. It also is frequently apparently open to the exterior at the posterior end by the accidental breaking of the thin, non-nervous dorsal wall of this region. The myelocoel is also known as the fourth ventricle.

The thalamocoel and myelocoel are connected by a narrow passage through the mesencephalon, the *aqueduct of Sylvius* (*iter, mesocoel*).

The optocoels are large cavities within the optic lobes which open into the aqueduct of Sylvius.

A large metacoel in the metencephalon opens into the myelocoel. The myelocoel is also continued into the corpora restiforma; posteriorly it joins the *central canal* which extends down the center of the spinal cord.

DISSECTION OF THE EYE. Remove one of the eyes from its orbit, and divide it into inner and outer halves by an equatorial cut around the eyeball (not directly through it, as this tears the lens from its fastenings). Place the halves under water and observe:

In the inner half:

The *posterior chamber,* the cavity of the eyeball which has been opened. During life it is filled by a gelatinous substance, the *vitreous humor.*

The *retina,* a delicate yellowish-white membrane lining the interior of the eye, loosely attached to the outer coats except at the point of entrance of the optic nerve.

The *choroid coat,* a thin, black membrane outside the retina. It can be pulled away from the outer coat quite easily except near the optic nerve.

The *sclerotic coat,* the outer coat of the eye. This is composed of connective tissue having an almost cartilaginous consistency, is only slightly pigmented, and is somewhat translucent. The muscles of the eye are inserted upon the sclerotic.

In the outer half:

The *ora serrata,* an irregular line along which the retina ends.

The *iris,* a fold of the choroid extending inward like a shelf, and

perforated centrally to form the pupil. Around the iris the choroid is folded radially into the *ciliary processes.*

The *lens,* a spherical body, transparent and elastic during life, but opaque and hard in preserved specimens. It projects into the pupil and is suspended from the ciliary processes by a delicate membrane, the *suspensory ligament.*

The *anterior chamber,* in front of the iris and lens, filled with a watery fluid, the *aqueous humor.*

The transparent *cornea,* forming the outer side of the eyeball, continuous with the sclerotic.

Take out the other eye and cut it in two by a section through the pupil and optic nerve. Review the relation of the parts.

THE SKELETON

There seems to be no easy way of cleaning the skeleton of dogfish which have been preserved in formalin or alcohol, the only procedure being to cut, pick, and scrape the flesh away from the skeleton. Time and patience are required, but if these are allowed there is no reason why all the parts of the skeleton cannot be thoroughly studied. Specimens which have been preserved in brine are more easily skeletonized.

The skeleton is entirely composed of cartilage which, in large species of elasmobranchs and in old individuals of small species, becomes impregnated with lime salts, in some cases to such an extent as to resemble soft bone.

The parts of the skeleton are frequently grouped under two heads: the *axial skeleton,* comprising the skull and vertebral column; and the *appendicular skeleton,* including the pectoral and pelvic girdles and the skeleton of the fins.

Vertebral column. The vertebral column is divided into two regions, thoracic and caudal, distinguished by the slightly different character of the vertebrae. Remove the muscle and connective tissue from the vertebral column for a short distance anterior to the first dorsal fin. Care is required not to cut away small cartilages occupying the positions of ribs. Now remove from the body about two inches of the portion of the column exposed with any cartilaginous parts which may be attached to the vertebrae. The vertical column is made up of segments, called *vertebrae.* Each vertebra consists of a large ventral mass, the centrum, and an arch, the neural arch, roofing over the dorsal surface of the centrum; the arch is composed of several small plates of cartilage. The opening enclosed by each centrum and its neutral arch is the vertebral foramen; the joined vertebral foramina form the neural canal, which is occupied by the spinal cord.

Separate one of the vertebrae from the rest. The centrum is deeply concave at each end; such a centrum is termed amphicoelous. At the middle of the centrum the concavities meet and thus a canal is formed through it. This canal and the spaces between the ends of adjoining vertebrae are filled by the remains of the notochord, a rather pulpy structure extending from end to end of the vertebral column.

The concave faces of the vertebrae consist of much firmer cartilage than the remaining portions, sometimes even calcified. Make a transverse section through the middle of a centrum and observe the relations of the parts.

On each side of the centrum, near the ventral edge, is a plate-

like projection, the transverse process. Attached to the extremity of this is a slender cartilaginous *rib.*

Each *neural arch* is made up of two distinguishable sets of plates. The first consists of a pair of broad *neural plates* extending upward from each side of the centrum and uniting with each other dorsally. Between the neural plates of two successive vertebrae is a pair (one on each side) of *intercalary plates* which also unite over the neural canal. The intercalary plates are over the joint between the centra. Neural and intercalary plates together make the lateral and dorsal walls of the neural canal. The relations of these plates can sometimes be seen best when the neural arch is cleaned, then cut away from the centrum, and looked through toward the light.

In the lower part of each neural plate is a small foramen which allows the passage of the ventral root of the spinal nerve. A foramen for the dorsal root is found at about the middle of the intercalary plate.

Clean and remove some of the caudal vertebrae from the region just back of the cloaca. In general they have nearly the same structure and relations as the thoracic vertebrae, but have no transverse processes and the plates of the neural arches are not so distinct. There is also added a ventral arch similar in form to the neural arch. This is the *haemal arch,* in which lie the caudal aorta and vein. Its roof is the surface of the centrum, the sides are formed by pairs of plates which correspond in number to the centra, and unite with each other ventrally. Between the successive plates are openings for the passage of branches of the artery and vein.

In this region foramina for the roots of the spinal nerves are found only in every other pair of neural and intercalary plates. Toward the tip of the vertebral column the relation of the neural and intercalary plates to the centra becomes very irregular.

In Eugaleus the roof of the neural arch is formed by a row of small, diamond-shaped plates which fit in between the other two sets. As these plates correspond morphologically to the neural spines of higher vertebrates, they may receive that name here. It is probable that the dorsal portion of the arch in Squalus is composed of similar neural spine elements which have become fused with the neural and intercalary plates of each side.

SKULL. The skull is entirely cartilaginous, and comprises three principal divisions: (1) the *cranium,* an undivided mass of cartilage lodging the brain and the organs of smell, sight, and hearing; (2) the *jaws;* (3) the *visceral arches,* or skeletons of the gill-arches.

(1) The cranium. A blunt prolongation of the anterior extremity of the cranium forms the *rostrum,* which supports the soft tissues of the snout. At each side of the base of the rostrum the cranium widens abruptly. On the anterior face of the widened portion and below the posterior angles of the rostrum is a pair of protruding *olfactory capsules,* in which the olfactory sacs are enclosed. An oval aperture in the posterior wall of each capsule opens into the braincase and permits the passage of the olfactory nerve through the cranium.

Back of the olfactory capsules are large lateral cavities, the *orbits.* The dorsal edge of the orbit makes an overhanging ledge, known as the *supra-orbital crest.* The projecting anterior and posterior angles of the orbit are distinguished as the prae- and post-orbital processes.

The portions of the cranium back of the orbit and at the sides

of the braincase form large lateral projections (*auditory capsules*) containing the organs of hearing.

At the center of the nearly vertical posterior surface of the cranium is a large opening, the *foramen magnum,* through which the spinal cord passes.

At either side of and below the foramen magnum is a smooth articulatory surface (*occipital condyle*) articulating with the centrum of the first vertebra.

The flattened ventral surface of the posterior part of the cranium forms the roof of the mouth, or palate.

In the mid-dorsal line of the cranium, between the prae-orbital processes, is a small aperture opening into the brain cavity, the *epiphysial foramen.* It is closed during life by a tough, fibrous membrane. The stalk of the epiphysis extends to the under surface of this membrane.

Between the auditory capsules is a deep depression in the roof of the cranium in the floor of which can be seen the two small pores through which the ducti endolymphatici pass into the capsules. Close behind them are two larger openings for the perilymph ducts.

A pair of foramina passes through the inner edge of the prae-orbital process; these permit the passage of the ophthalmic branches of the trigeminal and facial nerves to the dorsal surface of the snout. Near the bottom of the inner wall of the orbit is the foramen of the optic nerve. In the postero-ventral angle of the orbit is the large trigemino-facial foramen for the exit of branches of the trigeminal and facial nerves; in front of it is the small oculomotor foramen. The extremely small foramen of the trochlear nerve is almost directly above the optic foramen, near the top of the inner wall of the orbit. Close below the trigemino-facial foramen is the small passage for the abducens nerve. Below the abducens foramen is the transbasal canal. Behind and below the trigemino-facial foramen are two foramina, through which pass the hyomandibular branches of the facial nerve. The foramen of the vagus nerve is close to the foramen magnum, upon the posterior surface of the cranium. The foramen of the glossopharyngeal nerve is lateral to that of the vagus, near the postero-lateral angle of the cranium.

The cranium of Eugaleus is much like that of Squalus, except that the rostrum is formed by three rods, two dorsal and one ventral, which arise from the front of the brain case and converge anteriorally until they meet and fuse. The olfactory capsules are much larger and of heavier cartilage than in Squalus. The auditory region similarly is more prominent.

(2) The jaws. The jaws in reality are the first pair of visceral or gill-arches, and in spite of the modification which has taken place this relation can be seen easily in the adult shark. The upper jaw consists of a pair of *palato-quadrate* cartilages, united medially by ligament, and bearing the upper series of teeth. A large hooked palatine process extends from each palato-quadrate cartilage upward along the inner wall of the orbit. The lower jaw likewise consists of a pair of *Meckel's cartilages,* united medially (the union is called the symphysis), and bearing the lower series of teeth. A pair of small labial cartilages, which support the edges of the labial pockets, lie at each corner of the mouth.

(3) Visceral arches. The first of the visceral arches is much larger and heavier than the rest. It is known as the *hyoid arch.* Each side of the arch consists of two rods of cartilage: (1) the *hyomandibular cartilage,* which articulates with a distinct facet on the lateral surface of the auditory capsule, and extends from here

downward, outward, and backward; (2) the *cerato-hyal* cartilage, which is movably articulated to the hyomandibular and extends downward, forward and inward. The ventral ends of the ceratohyals are united by a median, plate-like *basihyal.*

The palato-quadrate and Meckelian cartilages are suspended from the hyomandibular by several strong ligaments, the direct attachments of the jaws to the cranium being of soft connective tissue only. Both the hyomandibular and ceratohyal cartilages bear slender rods (*branchial rays*) on their posterior edges, which support the anterior wall of the first gill-pouch. Note the position of the spiracle between the mandibular and hyoid arches. The anterior wall of the spiracle is strengthened by two small, flat, vertical cartilages, probably homologous with the branchial rays of the gill-arches.

The remaining five visceral arches differ little in their construction. Dorsally, each has a flat, sickle-shaped *pharyngo-branchial* cartilage attached to the vertebral column by fibrous bands. The pharyngobranchials of the last two arches are fused. Ventrad to each pharyngobranchial is an *epibranchial* cartilage. The next segment of each arch is formed by the *ceratobranchial* cartilage. All the epibranchials and ceratobranchials except those of the fifth arch bear slender branchial rays. The ventral ends of the ceratobranchials articulate with each other, the first being attached to the ceratohyal by ligament. The second, third, and fourth arches have another more ventral series of cartilages, the *hypobranchials.* The lower ends of the hypobranchials are attached to a large median plate, the *basibranchial.* The fourth ceratobranchial joins the third hypobranchial, while the ceratobranchials of the fifth arch are attached to the basibranchial directly. The basibranchial is composed of two segments closely united by ligament; the anterior one narrow, the posterior broad and flat in front, tapering to a sharp point behind.

Short teeth of cartilage, called gill rakers, project into the pharynx from the inner edges of the arches.

A dorsal and a ventral series of *extra-branchial* cartilages, thin, slender plates, lie on the external side of each gill-arch.

Pectoral girdle and fin. Remove from the body the pectoral girdle, with the fins attached, and carefully scrape off the muscles from the cartilaginous parts. It will be found that the support of the fin is partly of cartilaginous plates and rods, partly of horny fibres (*dermal fin-rays*) which overlie the extremities of the cartilages and extend to the edges of the fin. These fibres are in two layers, one beneath the skin of each side. They are formed in the dermis. A similar arrangement of horny fibres is found in all the other fins.

The pectoral girdle passes across the ventral surface of the body and upward on each side to the level of the vertebral column. The stout ventral bar presents numerous facets for the origin and insertion of muscles. The articular surfaces for the pectoral fins are well up on the sides of the girdle. The slender dorsal end of each side of the girdle consists of a separate bar of cartilage, movably articulated to the lower portion. The ascending limb of the girdle, from the fin articulations to the base of the cartilage just mentioned, is called the *scapular portion;* the small bar is the *supra-scapular;* the ventral bar between the fin articulations is the *coracoid portion.*

The cartilaginous skeleton of the pectoral fin consists primarily of a row of three *basal* cartilages, all articulating proximally with the girdle. The middle basal is much the largest. Distal to the

basals are three rows of rod-like *radial* cartilages, the proximal row being articulated to the basals.

PELVIC GIRDLE AND FIN. Remove the pelvic girdle from the body with the pelvic fins attached, and clean away the muscles.

The pelvic girdle consists of an almost straight bar of cartilage, slightly thicker at its middle than at its ends, which lies transversely in the ventral wall of the abdomen. To each end is attached a long *basal* cartilage which lies in the fin, close to and parallel with its inner margin. A proximal series of slender *radial* cartilages is attached to the lateral side of the basal; a distal series of very short radials lies outside of the first series, while the portion of the fin beyond these is supported by the dermal fin rays.

FIRST DORSAL FIN. Remove the mass of muscles on both sides of the base of the fin down to the vertebral column. The principal cartilages of the fin lie in the median connective tissue septum which separates the dorsal musculature of the two sides of the body. The basal cartilages of the fin are attached to the vertebral column by means of this septum. It is best to remove the underlying portion of the column with the fin. The cartilages can then be scraped perfectly clean. The skeleton of the fin is composed of three rows of cartilages: (1) a basal row consisting of one very large, flat plate and two or three smaller ones posterior to it; (2) an intermediate row of several plates of nearly equal size; and (3) a distal row of several very small plates. The intermediate and distal rows extend beyond the body musculature into the base of the fin. The remainder of the fin is supported by the dermal rays. In front of the cartilages which have been mentioned is the strong spine of dentine (see p. 5), with its free portion sheathed by an enamel-like covering.

SECOND DORSAL FIN. Remove this from the body in the same manner as the first dorsal. Its structure follows the same general plan, the differences being minor ones of shape, size, and number of plates. Several thin cartilaginous plates are sometimes formed in the median septum in front of the spine.

CAUDAL FIN. Only one side of the caudal fin should be cleaned, as when both sides are cleaned there is danger of breaking the delicate cartilages. The cartilaginous skeleton of the caudal fin consists of a row of slender rods along the dorsal side of the vertebral column, extending to its tip. There are no cartilaginous elements in the fin ventral to the vertebral column. By far the greater part of the caudal fin is supported by the two layers of horny fin-rays only.

MUSCULATURE

Dissect the skin off the head, neck, and body to back of the pectoral fins. Observe first the musculature of the dorsal side of the neck and of the body back of the bases of the pectoral fins, noticing that it is composed of narrow, zigzag bands, called *myomeres.* Where these are fully developed they extend from the mid-dorsal to the mid-ventral line. Note carefully the relation of corresponding myomeres of the two sides, the exact course of a single myomere, and the direction of the muscle fibres in a typical myomere. Observe also that the muscles above the level of the vertebral column form a thick mass, which is frequently referred to as the dorsal musculature; the muscle below this level may be correspondingly referred to as the ventral musculature. As the muscles described below are dissected the mechanical effect of each should be determined.

Musculature of the head and neck. On the lateral and ventral surfaces of the neck the primary relations of the myomeres are much modified by the development of numerous special muscles, yet here and there traces of the metameric arrangement still show. Immediately beneath the skin is a thin sheet of muscle covering most of the ventral and lateral surfaces of the throat as far back as the pectoral girdle. On the ventral surface a triangular space is left in front of the pectoral bar; on the sides of the neck the sheet extends back to the last gill-cleft; dorsally, it reaches to the upper extremities of the gill pouches. This is the *constrictor superficialis* muscle. It is attached to fasciae dorsally and ventrally, and to the extra-branchial cartilages.

The constrictor superficialis consists of six metameric segments. The four posterior ones are distinctly limited by the gill-slits and extra-branchial cartilages. The second is anterior to the first gill-slit, the largest of all, with distinct dorsal and ventral portions extending forward above and below the jaws. The first is recognized as consisting of two distinct parts, on the dorsal and ventral surfaces of the head. The dorsal portion is a small curved muscle on the anterior wall of the spiracle, extending from the external surface of the auditory capsule to the inner surface of the lower jaw. It lies close against the levator marillae superioris (see below). On the ventral surface of the throat the posterior constrictor muscles of the two sides are separated by a large triangular area. In front of this the ventral portions of the first and second constrictors meet in a median aponeurosis, from which their fibres extend transversely, those of the first to the mandibular cartilage, those of the second to the hyoidean cartilage. The first constrictor lies ventral or superficially to, and largely covers the second. Reflect the first constrictor from the aponeurosis outward, and demonstrate the two layers of muscle. It will be noted that the second to sixth constrictors consist of united dorsal, lateral and ventral portions, while the first is reduced to widely separated dorsal and ventral parts.

On each side of the head, just outside the angle of the mouth, is a large, thick muscle arising from the lateral surface of the cranium, and inserted upon the outer surface of the mandible, the *adductor mandibularis.*

In front of the small dorsal constrictor superficialis 1, and scarcely separated from it, is the strong *levator maxillae superioris,* which extends from the lateral surface of the auditory capsule to the dorsal edge of the palatoquadrate cartilage.

Eugaleus. The dorsal portion of the *constrictor superficialis 2* reaches above the spiracle to the postorbital process. Reflecting it, the *adductor hyomandibulae* is seen behind the spiracle, arising from the upper part of the side of the auditory capsule and inserted on the end of the hyomandibular cartilage. The *levator palpebrae inferioris* arises under the origin of the levator hyomandibulae, and passes forward and downward between the spiracle and postorbital process, to insert in the posterior end of the lower eyelid. The *depressor palpebrae superioris* arises from the fascia dorsal to the spiracle, passes mediad to the levator palpebrae inferioris, upward and forward, to insert in the posterior end of the upper eyelid. Remove these muscles. The infraorbital canal passes mediad to the muscles of the eyelids. The *levator maxillae superioris* lies between the spiracle and the orbit. Behind it is a small slip of muscle extending from the anterior wall of the spiracle to the lateral surface of the auditory capsule which seems to represent the *constrictor superficialis dorsalis 1.*

A thin sheet of muscle covers the anterior face of each interbranchial septum. At the surface these pass into the constrictor

superficialis, and are evidently portions of the latter muscle, though they are named the *musculi interbranchiales*.

Above the constrictor superficialis, lying on the side of the neck between it and the dorsal musculature, is a broad *trapezius* muscle. It arises from the fascia covering the lateral surface of the dorsal musculature. Its fibres pass obliquely downward and backward, mediad to the posterior gill-pouches, to insert upon the anterior edge of the scapular portion of the pectoral girdle. The anterior portion of the trapezius is also inserted upon the epibranchial of the fifth gill-arch.

Just in front of the mouth is a pair of strong muscles (*levator labialis superioris*), each arising from the ventral surface of the cranium close to the median line. They pass into strong tendons which are inserted among the fibres of the ventral portion of the adductor mandibulae. The muscle mass in front of the mouth and the lower part of the adductor mandibularis thus form the two bellies of a digastric muscle, with the tendon between them.

*Remove the ventral portions of the first and second superficial constrictors and clear the mass of muscles lying between the coracoid portion of the pectoral girdle and the mandible. Immediately in front of the girdle are two large muscles, the *coraco-arcuales communes*, whose fibres run inward and forward. These muscles cover the ventral surface of the pericardium, to the wall of which their median fibres are attached, while the lateral fibres are attached around the ventral ends of the gill-arches.

In front of the coraco-arcuales communes are three large longitudinal muscles. The median, unpaired one, arising from the fascia between the coraco-arcuales communes and inserted upon the posterior surface of the lower jaw, is the *coraco-mandibularis*. The other two, which lie dorsal to and outside of the coraco-mandibularis, are the *coraco-hyoidei*. They arise from the fasciae covering the anterior ends of the coraco-arcuales communes and posterior parts of the coraco-branchiales, and insert upon the basihyal.

Dissect out the coraco-mandibularis and coroaco-hyoidei, noting particularly the form and place of origin of the latter. Dorsal to the coraco-hyoidei are the first divisions of the right and left *coraco-branchialis* muscles, which arise from fascia covering the anterior ends of the coraco-arcuales communes, and are inserted upon the ventral extremity of the ceratohyal cartilage. Notice that they pass dorsad to the anterior branches of the aorta, and that the aorta itself can be exposed between them.

Remove the coraco-arcualis communis by dissecting it from the pectoral girdle and reflecting it forward. The other four divisions of the coraco-branchialis are now revealed, attached to the lateral surface of the pericardium and the lateral portion of the coracoid. The divisions of the muscle are clearly separated only near their insertions. The second, third, and fourth coraco-branchials are attached to the hypobranchial cartilages of the second, third and fourth visceral arches. The fifth division is inserted upon the lateral portion of the basibranchial and the expanded medial end of the fifth ceratobranchial.

The first aortic branch passes ventral to the first coraco-branchial. *The second* aortic branch passes between the first and second

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*The coraco-mandibularis, coraco-hyodeus, coraco-arcualis communis, and coraco-branchialis muscles should be dissected as a preliminary operation to following the ventral aorta and its branches.

coraco-branchials. *The third* aortic branch passes between the second and third coraco-branchials. *The fourth* aortic branch passes between the third and fourth coraco-branchials.

Expose the dorsal ends of the gill arches by clearing away muscles and other tissues between the gill pouches and the spinal column. Two sets of four small muscles (interarcuales) will be found connected with the branchial cartilages. The second, third and fourth *medial interarcuales* extend from the posterior surfaces of pharyngo-branchial cartilages 1, 2, and 3, to the dorsal surfaces of pharyngo-branchials 2, 3, 4, and 5. The first medial interarcuale arises from the under surface of the cranium and inserts on the upper end of the first pharyngo-branchial.

The *lateral interarcuales* lie immediately below the medials. The first has a double origin, most of the fibres arising from the lower part of the posterior edge of the first pharyngo-branchial; a smaller bundle from the anterior edge of the second pharyngo-branchial. Its insertion is along the dorsal surface of the first epibranchial cartilage. The second and third lateral inter-arcuales are like the first, but since the fourth and fifth pharyngo-branchials are fused, the origin of the fourth lateral interarcuale is not divided.

The circular muscles of the oesophagus are strongly attached to the last pharyngo-branchial.

Musculature of the pectoral fin. The dorsal muscle of the fin (*levator-retractor*) arises mostly from the scapular portion of the girdle, with a small part arising from the fascia covering the lateral musculature of the body. It is attached in fasciculi to the dorsal surfaces of the cartilaginous rays. The ventral muscle (*depressor-protractor*) arises from the median portion of the girdle and is inserted upon the cartilaginous rays in similar fasciculi. A portion of the lateral body muscles is inserted upon the scapular portion of the girdle.

Musculature of the pelvic fin. Ventral surface: An *adductor* muscle has origin upon the postero-lateral edge of the girdle; it is inserted upon the antero-medial surface of the basal cartilage of the fin. The *depressor* muscle consists of small fasciculi, each corresponding to a cartilaginous ray. They arise from the postero-lateral surface of the basal cartilage and are inserted upon the distal extremities of the rays.

Dorsal surface: The *abductor* arises from the fascia covering the trunk muscles, and inserts upon the fascia covering the intrinsic muscles of the dorsal side of the fin. These latter (*levatores*) are arranged in exactly the same manner as the fasciculi of the depressor.

Musculature of the dorsal fins. A sheet of muscle is attached to each side of the anterior dorsal fin, extending nearly up to the bases of the dermal fin-rays. This muscle passes downward between the dorsal body musculature of the two sides. Part of the fibres arise from the fasciae covering the medial surfaces of the body muscles, part from the basal cartilage of the fin itself. They are inserted upon the lateral surfaces of the broad cartilaginous fin-rays. The muscles of the posterior dorsal fin are exactly similar in arrangement.

Musculature of the caudal fin. There is no special musculature for the dorsal portion. A narrow, band-like muscle is found on each side of the ventral portion, widest above the triangular ventral lobe. The fibres of this muscle arise upon the flattened, expanded ends of the haemal spines. They pass obliquely backward and upward to be inserted in the fascia underlying the skin.